ELECTRICAL CONNECTORS AND METHODS FOR USING THE SAME

Related Application(s)

The present application is a continuation-in-part application (CIP) of and claims priority from U.S. Patent Application Serial No. 10/324,817, filed December 20, 2002, the disclosure of which is hereby incorporated herein by reference in its entirety.

Field of the Invention

The present invention relates to electrical connectors and methods for using the same and, more particularly, to environmentally protected electrical connectors and methods for forming environmentally protected connections.

Background of the Invention

Multi-tap or busbar connectors are commonly used to distribute electrical power, for example, to multiple residential or commercial structures from a common power supply feed. Busbar connectors typically include a conductor member formed of copper or aluminum housed in a polymeric cover. The conductor member includes a plurality of cable bores. The cover includes a plurality of ports, each adapted to receive a respective cable and to direct the cable into a respective one of the cable bores. A set screw is associated with each cable bore for securing the cables in the respective bores and, thereby, in electrical contact with the conductor member.

The busbar assemblies as described above can be used to electrically connect two or more cables. For example, a feed cable may be secured to the

busbar connector through one of the ports and one or more branch or tap circuit cables may be connected to the busbar connector through the other ports, to distribute power from the feed cable. Busbar connectors of this type provide significant convenience in that cables can be added and removed from the connection as needed.

Power distribution connections as discussed above are typically housed in an above-ground cabinet or a below-grade box. The several cables are usually fed up through the ground and the connection (including the busbar connector) may remain unattached to the cabinet or box (i.e., floating within the cabinet). The connections may be subjected to moisture, and may even become submerged in water. If the conductor member and the conductors are left exposed, water and environmental contaminants may cause corrosion thereon. Moreover, the conductor member is often formed of aluminum, so that water may cause oxidation of the conductor member. Such oxidation may be significantly accelerated by the relatively high voltages (typically 120 volts to 1000 volts) employed. In order to reduce or eliminate exposure of the conductor member and the conductor portions of the cables to water, some known busbar designs include elastomeric boots or caps. These caps or boots may be difficult or inconvenient to install properly, particularly in the field, and may not provide reliable seals.

Summary of the Invention

According to embodiments of the present invention, a busbar assembly for electrically connecting a plurality of conductors includes a housing defining an interior cavity and first and second ports. The first and second ports each include a conductor passage and communicate with the interior cavity. The conductor passages are each adapted to receive a conductor therethrough. An electrically conductive busbar conductor member is disposed in the interior cavity. At least one holding mechanism is provided to selectively secure each of the conductors to the busbar conductor member for electrical contact therewith. Sealant is disposed in the conductor passages of each of the first and second ports. The sealant is adapted for insertion of the conductors therethrough such that the sealant provides a seal about the inserted conductors. The sealant may be a gel.

According to method embodiments of the present invention, a method is provided for forming a connection between an electrical connection between a busbar assembly and first and second conductors, the busbar assembly including a housing, an electrically conductive busbar conductor member, at least one holding mechanism and a sealant, the housing defining an interior cavity and first and second ports each including a conductor passage and communicating with the interior cavity, the busbar member being disposed in the interior cavity, the sealant being disposed in the conductor passages of each of the first and second ports. The method includes inserting each of the first and second conductors through a respective one of the conductor passages and the sealant disposed therein and into the interior cavity such that the sealant provides a seal about the first and second conductors. The method further includes selectively securing each of the conductors to the busbar conductor member for electrical contact therewith using the at least one holding mechanism.

According to embodiments of the present invention, an electrical connector for use with a conductor includes a housing defining a port. The port includes an entrance opening, an exit opening, and a conductor passage extending between and communicating with the entrance and exit openings. The conductor passage is adapted to receive the conductor therethrough. A sleeve member is disposed in the conductor passage and defines a sleeve passage. Sealant is disposed in the sleeve passage. The sealant is adapted for insertion of the conductor therethrough such that the sealant provides a seal about the inserted conductor. The sealant may be a gel.

According to further embodiments of the present invention, an insert assembly for providing a seal to an electrical connector, the electrical connector including a housing defining a port, the port including an entrance opening, an exit opening, and a conductor passage extending between and communicating with the entrance and exit openings, the conductor passage being adapted to receive a conductor therethrough, includes a sleeve member adapted to be inserted into the conductor passage. The sleeve member defines a sleeve passage. Sealant is disposed in the sleeve passage. The sealant is adapted for insertion of the conductor therethrough such that the sealant provides a seal about the inserted conductor. The sealant may be a gel.

According to method embodiments of the present invention, a method is provided for providing a seal to an electrical connector, the electrical connector including a housing defining a port, the port including an entrance opening, an exit opening, and a conductor passage extending between and communicating with the entrance and exit openings, the conductor passage being adapted to receive a conductor therethrough. The method includes inserting an insert member into the conductor passage. The insert member includes a sleeve member defining a sleeve passage. The sleeve member further includes sealant disposed in the sleeve passage. The sealant is adapted for insertion of the conductor therethrough such that the sealant provides a seal about the inserted conductor.

According to further embodiments of the present invention, an electrical connector for use with a conductor is provided. The electrical connector defines an access opening and an access passage communicating with the access opening and includes a holding mechanism operable to secure the conductor to the electrical connector. The holding mechanism is accessible through the access opening and the access passage. Access sealant is disposed in the access passage and is adapted to seal the access passage. The access sealant may be a gel.

According to further embodiments, an electrical connector for use with a conductor includes a housing defining a port. The port includes an entrance opening, an exit opening, and a conductor passage extending between and communicating with the entrance and exit openings. The conductor passage is adapted to receive the conductor therethrough. Sealant is disposed in the conductor passage. The sealant is adapted for insertion of the conductor therethrough such that the sealant provides a seal about the inserted conductor. A penetrable closure wall extends across the conductor passage.

According to further method embodiments of the present invention, a method is provided for forming a connection between an electrical connector and a conductor, the electrical connector including a housing defining a port, the port including an entrance opening, an exit opening and a conductor passage extending between and communicating with the entrance and exit openings, the electrical connector further including sealant disposed in the conductor passage and a penetrable closure wall extending across the conductor passage. The method includes inserting the conductor through the conductor passage and the sealant

disposed therein such that the sealant provides a seal about the conductor. The closure wall is penetrated with the conductor.

Objects of the present invention will be appreciated by those of ordinary skill in the art from a reading of the figures and the detailed description of the preferred embodiments which follow, such description being merely illustrative of the present invention.

Brief Description of the Drawings

Figure 1 is a perspective view of an electrical connection assembly including a busbar assembly according to embodiments of the present invention and a pair of cables, wherein the cables are exploded from the busbar assembly;

Figure 2 is an exploded, perspective view of the busbar assembly of **Figure 1**;

Figure 3 is a cross-sectional view of the busbar assembly of **Figure 1** taken along the line **3-3** of **Figure 1**;

Figure 4 is a cross-sectional view of the busbar assembly of **Figure 1** taken along the same line as the view of **Figure 3**, and wherein a cable is installed in the busbar assembly;

Figure 5 is an exploded, perspective view of a busbar assembly according to further embodiments of the present invention;

Figure 6 is a cross-sectional view of the busbar assembly of **Figure 5** taken along the line **6-6** of **Figure 5**;

Figure 7 is a rear, perspective view of a sleeve member forming a part of the busbar assembly of **Figure 5**;

Figure 8 is a cross-sectional view of the busbar assembly of **Figure 5** taken along the line **8-8** of **Figure 5**;

Figure 9 is a cross-sectional view of the busbar assembly of **Figure 5** taken along the same line as the view of **Figure 8**, and wherein a cable is installed in the busbar assembly;

Figure 10 is an exploded, perspective view of a busbar assembly according to further embodiments of the present invention;

Figure 11 is a cross-sectional view of the busbar assembly of **Figure 10** taken along the line **11-11** of **Figure 10**;

Figure 12 is an exploded, perspective view of a busbar assembly according to further embodiments of the present invention;

Figure 13 is a cross-sectional view of the busbar assembly of **Figure 12** taken along the line **13-13** of **Figure 12**; and

Figure 14 is a cross-sectional view of a busbar assembly according to further embodiments of the present invention.

Detailed Description of the Embodiments of the Invention

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like numbers refer to like elements throughout.

With reference to **Figures 1-4**, a connector or busbar assembly **100** according to embodiments of the present invention is shown therein. The busbar assembly **100** may be used to electrically connect a plurality of electrical connectors, such as conductors **5A** and **7A** of cables **5** and **7** (which further include electrically insulative sheaths or covers **5B**, **7B**), as shown in **Figures 1** and **4**. The busbar assembly **100** may provide an environmentally protected and, preferably, watertight connector and connection. For example, the busbar assembly **100** may be used to electrically connect the conductors of a power feed cable and one or more branch or tap cables, while preventing the conductive portions of the cables and the busbar assembly **100** from being exposed to surrounding moisture or the like.

Turning to the busbar assembly **100** in more detail, the busbar assembly **100** includes a busbar conductor member **110**, a cover assembly **120**, a plurality of set screws **102** (only two shown in **Figure 2**), and a mass of sealant **160**. The cover assembly **120** includes a rear cover member **130** and a front cover member **140**. The cover assembly **120** defines an interior cavity **122** within which the conductor member **110** is disposed. The interior cavity **122** is environmentally protected.

The conductor member **110** includes four cable or conductor bores **112**, each having a front opening **114**. The conductor bores **112** are sized and shaped to receive the conductors **5A, 7A**. Four threaded bores **116** extend orthogonally to and intersect respective ones of the conductor bores **112**. The conductor member **110** may be formed of any suitable electrically conductive material. In some embodiments, the conductor member **110** is formed of copper or aluminum. In certain preferred embodiments, the conductor member **110** is formed of aluminum. The conductor member **110** may be formed by molding, stamping, extrusion and/or machining, or by any other suitable process(es).

The rear cover member **130** includes a body portion **132**. A plurality of transversely extending ribs **133** project into the interior cavity **122** from the body portion **132**. Four access ports **134** are provided on the body portion **132**. Each access port **134** includes an access tube **134A** defining an access passage **134B**. The access passage **134B** communicates with an access opening **134C** and the interior cavity **122**. A perimeter flange **136** extends about the body portion **132** and defines a perimeter channel **136A**. A plurality of latch slots **138** are formed in the flange **136**.

The front cover member **140** includes a body portion **142**. A pair of transversely extending spacer ribs **143 (Figure 3)** extend transversely to the body portion **142**. Four conductor or cable ports **144** are provided on the body portion **142**. Each port **144** includes a cable tube **144A** defining a cable passage **144B**. The cable passage **144B** communicates with an entrance opening **144C** and an exit opening **144D**. A frangible closure wall **150** extends across the passage **144B** between the openings **144C** and **144D**.

A perimeter flange **146** surrounds and projects rearwardly from the body portion **142**. A plurality of barbed latch projections **148** extend rearwardly from the flange **146**.

Four plugs or caps **152** are joined to the body portion **142** by a flexible connecting portion **154**. The caps **152** are sized and shaped to fit in respective ones of the access passageways **134B** and access openings **134C**. An O-ring (e.g., formed of an elastomer or the like) is provided on each cap **152** to provide a seal between the caps **152** and the access ports **134**.

Preferably, the front cover member **140** is integrally formed and the rear cover member **130** is integrally formed. The cover members **130**, **140** may be formed of any suitable electrically insulative material. Preferably, the cover members **130**, **140** are formed of a molded polymeric material. More preferably, the cover members **130**, **140** are formed of polypropylene, polyethylene or a thermoplastic elastomer. The cover members **130**, **140** may be formed of a flame retardant material, and may include a suitable additive to make the cover members flame retardant.

Each of four set screws **102** (only two shown in **Figure 2**) is threadedly installed in a respective one of the threaded bores **116**. Each of the screws **102** includes a socket **102A** which may be adapted to receive a driver **9** (**Figure 4**), for example.

As best seen in **Figures 2** and **3**, the sealant **160** is disposed in the cover assembly **120**. More particularly, a body sealant portion **164** of the sealant **160** is disposed in a front portion of the interior cavity **122**. A plurality of port sealant portions **162** are disposed in respective ones of the ports **144**. In some embodiments and as illustrated, each port sealant portion **162** extends from the inner side of the closure wall **150** to the exit opening **144D** of the associated port **144** and is contiguous with the body sealant portion **164**. The sealant portion **164** includes a perimeter portion **166** that is disposed in the channel **136A** to form a surrounding seal between the cover members **130**, **140**.

According to some embodiments of the invention, the sealant **160** is a gel. The term "gel" has been used in the prior art to cover a vast array of materials from greases to thixotropic compositions to fluid-extended polymeric systems. As used herein, "gel" refers to the category of materials which are solids extended by a fluid extender. The gel may be a substantially dilute system that exhibits no steady state flow. As discussed in Ferry, "Viscoelastic Properties of Polymers," 3rd ed. P. 529 (J. Wiley & Sons, New York 1980), a polymer gel may be a cross-linked solution whether linked by chemical bonds or crystallites or some other kind of junction. The absence of the steady state flow may be considered to be the key definition of the solid-like properties while the substantial dilution may be necessary to give the relatively low modulus of gels. The solid nature may be achieved by a continuous network structure formed in the material generally

through crosslinking the polymer chains through some kind of junction or the creation of domains of associated substituents of various branch chains of the polymer. The crosslinking can be either physical or chemical as long as the crosslink sites may be sustained at the use conditions of the gel.

Preferred gels for use in this invention are silicone (organopolysiloxane) gels, such as the fluid-extended systems taught in U.S. Pat. No. 4,634,207 to Debbaut (hereinafter "Debbaut '207"); U.S. Pat. No. 4,680,233 to Camin et al.; U.S. Pat. No. 4,777,063 to Dubrow et al.; and U.S. Pat No. 5,079,300 to Dubrow et al. (hereinafter "Dubrow '300"), the disclosures of which are hereby incorporated herein by reference. These fluid-extended silicone gels may be created with nonreactive fluid extenders as in the previously recited patents or with an excess of a reactive liquid, e.g., a vinyl-rich silicone fluid, such that it acts like an extender, as exemplified by the Sylgard® 527 product commercially available from Dow-Corning of Midland, Michigan or as disclosed in U.S. Pat. No. 3,020,260 to Nelson. Because curing is involved in the preparation of these gels, they are sometimes referred to as thermosetting gels. An especially preferred gel is a silicone gel produced from a mixture of divinyl terminated polydimethylsiloxane, tetrakis(dimethylsiloxy)silane, a platinum divinyltetramethyldisiloxane complex, commercially available from United Chemical Technologies, Inc. of Bristol, Pennsylvania, polydimethylsiloxane, and 1,3,5,7-tetravinyltetra-methylcyclotetrasiloxane (reaction inhibitor for providing adequate pot life).

Other types of gels may be used, for example, polyurethane gels as taught in the aforementioned Debbaut '261 and U.S. Pat. No. 5,140,476 Debbaut (hereinafter "Debbaut '476") and gels based on styrene-ethylene butylenestyrene (SEBS) or styrene-ethylene propylene-styrene (SEPSS) extended with an extender oil of naphthenic or nonaromatic or low aramatic content hydrocarbon oil, as described in U.S. Pat. No. 4,369,284 to Chen; U.S. Pat. No. 4,716,183 to Gamarra et al.; and U.S. Pat. No. 4,942,270 to Gamarra. The SEBS and SEPS gels comprise glassy styrenic microphases interconnected by a fluid-extended elastomeric phase. The microphase-separated styrenic domains serve as the junction points in the systems. The SEBS and SEPS gels are examples of thermoplastic systems.

Another class of gels which may be considered are EPDM rubber based gels, as described in U.S. Pat. No. 5,177,143 to Chang et al.

Yet another class of gels which may be suitable are based on anhydride-containing polymers, as disclosed in WO 96/23007. These gels reportedly have good thermal resistance.

The gel may include a variety of additives, including stabilizers and antioxidants such as hindered phenols (e.g., Irganox™ 1076, commercially available from Ciba-Geigy Corp. of Tarrytown, New York), phosphites (e.g., Irgafos™ 168, commercially available from Ciba-Geigy Corp. of Tarrytown, New York), metal deactivators (e.g., Irganox™ D1024 from Ciba-Geigy Corp. of Tarrytown, New York), and sulfides (e.g., Cyanox LTDP, commercially available from American Cyanamid Co. of Wayne, New Jersey), light stabilizers (i.e., Cyasorb UV-531, commercially available from American Cyanamid Co. of Wayne, New Jersey), and flame retardants such as halogenated paraffins (e.g., Bromoklor 50, commercially available from Ferro Corp. of Hammond, Indiana) and/or phosphorous containing organic compounds (e.g., Fyrol PCF and Phosflex 390, both commercially available from Akzo Nobel Chemicals Inc. of Dobbs Ferry, New York) and acid scavengers (e.g., DHT-4A, commercially available from Kyowa Chemical Industry Co. Ltd through Mitsui & Co. of Cleveland, Ohio, and hydrotalcite). Other suitable additives include colorants, biocides, tackifiers and the like described in "Additives for Plastics, Edition 1" published by D.A.T.A., Inc. and The International Plastics Selector, Inc., San Diego, Calif.

The hardness, stress relaxation, and tack may be measured using a Texture Technologies Texture Analyzer TA-XT2 commercially available from Texture Technologies Corp. of Scarsdale, New York, or like machines, having a five kilogram load cell to measure force, a 5 gram trigger, and ¼ inch (6.35 mm) stainless steel ball probe as described in Dubrow '300, the disclosure of which is incorporated herein by reference in its entirety. For example, for measuring the hardness of a gel a 60mL glass vial with about 20 grams of gel, or alternately a stack of nine 2 inch x 2 inch x 1/8" thick slabs of gel, is placed in the Texture Technologies Texture Analyzer and the probe is forced into the gel at the speed of 0.2 mm per sec to a penetration distance of 4.0 mm. The hardness of the gel is the force in grams, as recorded by a computer, required to force the probe at that speed

to penetrate or deform the surface of the gel specified for 4.0 mm. Higher numbers signify harder gels. The data from the Texture Analyzer TA-XT2 may be analyzed on an IBM PC or like computer, running Microsystems Ltd, XT.RA Dimension Version 2.3 software.

The tack and stress relaxation are read from the stress curve generated when the XT.RA Dimension version 2.3 software automatically traces the force versus time curve experienced by the load cell when the penetration speed is 2.0 mm/second and the probe is forced into the gel a penetration distance of about 4.0 mm. The probe is held at 4.0 mm penetration for 1 minute and withdrawn at a speed of 2.00 mm/second. The stress relaxation is the ratio of the initial force (F_i) resisting the probe at the pre-set penetration depth minus the force resisting the probe (F_f) after 1 min divided by the initial force F_i, expressed as a percentage. That is, percent stress relaxation is equal to

$$\frac{(F_i - F_f)}{F_i} \times 100\%$$

where F_i and F_f are in grams. In other words the stress relaxation is the ratio of the initial force minus the force after 1 minute over the initial force. It may be considered to be a measure of the ability of the gel to relax any induced compression placed on the gel. The tack may be considered to be the amount of force in grams resistance on the probe as it is pulled out of the gel when the probe is withdrawn at a speed of 2.0 mm/second from the preset penetration depth.

An alternative way to characterize the gels is by cone penetration parameters according to ASTM D-217 as proposed in Debbaut '261; Debbaut '207; Debbaut '746; and U.S. Pat. No. 5,357,057 to Debbaut et al., each of which is incorporated herein by reference in its entirety. Cone penetration ("CP") values may range from about 70 (10^{-1} mm) to about 400 (10^{-1} mm). Harder gels may generally have CP values from about 70 (10^{-1} mm) to about 120 (10^{-1} mm). Softer gels may generally have CP values from about 200 (10^{-1} mm) to about 400 (10^{-1} mm), with particularly preferred range of from about 250 (10^{-1} mm) to about 375 (10^{-1} mm). For a particular materials system, a relationship between CP and Voland gram hardness can be developed as proposed in U.S. Pat. No. 4,852,646 to Dittmer et al.

Preferably, the gel has a Voland hardness, as measured by a texture analyzer, of between about 5 and 100 grams force, more preferably of between about 5 and 30 grams force, and, most preferably, of between about 10 and 20 grams force. Preferably, the gel has an elongation, as measured by ASTM D-638, of at least 55%, more preferably of at least 100%, and most preferably of at least 1,000%. Preferably, the gel has a stress relaxation of less than 80%, more preferably of less than 50%, and most preferably of less than 35%. The gel has a tack preferably greater than about 1 gram, more preferably greater than about 6 grams, and most preferably between about 10 and 50 grams. Suitable gel materials include POWERGEL sealant gel available from Tyco Electronics Energy Division of Fuquay-Varina, NC under the RAYCHEM brand.

Alternatively, the sealant **160** may be silicone grease or a hydrocarbon-based grease.

Referring to **Figure 4**, the busbar assembly **100** may be used in the following manner to form an electrical connection assembly **101** as shown therein. The connection assembly **101** includes the busbar assembly **100** and the cable **5**, and may include additional cables secured to the busbar assembly **100** in the manner described immediately hereinafter.

With the set screw **102** in a raised position as shown in **Figure 3**, the cable **5** is inserted into the selected port **144**. More particularly, the terminal end of the cable **5** (which has an exposed portion of the conductor **5A**) is inserted through the entrance opening **144C**, the passage **144A**, and the exit opening **144D**, and into the conductor bore **112**. In doing so, the closure wall **150** is ruptured by the cable end and the sealant **160** is displaced as shown in **Figure 4**. Preferably and as shown, the busbar assembly **100** is configured such that the interior cavity **122** includes a volume of a compressible gas (e.g., air) to allow insertion of the cable **5** without a proportionate displacement of the sealant **160** out of the interior cavity **122**.

The set screw **102** is then rotatively driven (for example, using the driver **9**) into the threaded bore **116** to force the exposed portion of the conductor **5A** against the opposing wall of the bore **112**. The cap **152** is then replaced over the access opening **134C**.

In this manner, the cable **5** is mechanically secured to or captured within the busbar assembly **100** and electrically connected to the conductor member **110**.

One or more additional cables may be inserted through the other ports **144** and secured using the other set screws **102**. In this manner, such other cables are thereby electrically connected to the cable **5** and to one another through the conductor member **110**.

When, as preferred, the sealant **160** is a gel, the cable **5** and the tube **144A** apply a compressive force to the sealant **160** as the cable **5** is inserted into the busbar assembly **100**. The gel is thereby elongated and is generally deformed and substantially conforms to the outer surface of the cable **5** and to the inner surface of the tube **144A**. The elongated gel may extend into and through the conductor bore **112**. Moreover, the elongated gel may extend beyond the conductor member **110** into an expansion chamber **135** created by the ribs **133**. Some shearing of the gel may occur as well. Preferably, at least some of the gel deformation is elastic. The restoring force in the gel resulting from this elastic deformation causes the gel to operate as a spring exerting an outward force between the tube **144** and the cable **5**.

The ruptured closure wall **150** may serve to prevent or limit displacement of the gel sealant **160** out of the port **144** toward the entrance opening **144C**, thereby promoting displacement of the gel into the interior cavity **122**. Preferably, the busbar assembly is adapted such that, when the cable **5** is installed, the gel has an elongation at the interface between the gel **160** and the inner surface of the tube **144A** of at least 20%.

Each of the closure walls **150** serves as a dam for the gel or other sealant **160** in use. Additionally, the closure walls **150** serve as mechanical covers (for example, to prevent or reduce the entry of dust and the like). Moreover, the closure walls **150** may serve as dams for the gel or other sealant **160** during manufacture, as described below. It will be appreciated that, in some embodiments of the present invention, the closure walls **150** can be omitted.

The busbar assembly **100** may provide a reliable (and, in at least some embodiments, moisture-tight) seal between the busbar assembly **100** and the cable **5**, as well as any additional cables secured in the ports **144**. The sealant **160**, particularly gel sealant, may accommodate cables of different sizes within a prescribed range. The ports **144** which do not have cables installed therein are likewise sealed by the sealant **160**. Upon removal of a cable, the associated port **144** may be resealed by the re-formation of the gel sealant **160**.

Various properties of the gel, as described above may ensure that the gel sealant **160** maintains a reliable and long lasting hermetic seal between the tube **144A** and the cable **5**. The elastic memory of and the retained or restoring force in the elongated, elastically deformed gel generally cause the gel to bear against the mating surfaces of the cable **5** and the interior surface of the tube **144A**. Also, the tack of the gel may provide adhesion between the gel and these surfaces. The gel, even though it is cold-applied, is generally able to flow about the cable **5** and the connector **100** to accommodate their irregular geometries.

Preferably, the sealant **160** is a self-healing or self-amalgamating gel. This characteristic, combined with the aforementioned compressive force between the cable **5** and the tube **144A**, may allow the sealant **160** to re-form into a continuous body if the gel is sheared by the insertion of the cable **5** into the connector **100**. The gel may also re-form if the cable **5** is withdrawn from the gel.

The sealant **160**, particularly when formed of a gel as described herein, may provide a reliable moisture barrier for the cable **5** and the conductor member **110**, even when the connection **101** is submerged or subjected to extreme temperatures and temperature changes. Preferably, the cover members **130**, **140** are made from an abrasion resistant material that resists being punctured by the abrasive forces.

The gel may also serve to reduce or prevent fire. The gel is typically a more efficient thermal conductor than air and, thereby, may conduct more heat from the connection. In this manner, the gel may reduce the tendency for overheating of the connection **101** that might otherwise tend to deteriorate the cable insulation and cause thermal runaway and ensuing electrical arcing at the connection **101**. Moreover, the gel may be flame retardant.

The busbar assembly **100** may be formed in the following manner. If the sealant **160** requires curing, such as a curable gel, the sealant may be cured *in situ*. The front cover member **140** is oriented vertically with the body portion **142** over the ports **144**. Liquid, uncured sealant is dispensed into the front cover member **140**, such that it fills the cable passages **144B** above the closure walls **150** and also fills a portion of the body member **142** (the flange **146** serving as a surrounding side dam). The sealant is then cured *in situ*.

The cover members **130**, **140** are then joined and interlocked by means of the latch slots **138** and the latch projections **148** about the conductor member **110**. The

set screws **102** are installed in the threaded bores **116** through the access ports **134**. The O-rings **156** are installed on the caps **152**.

According to some embodiments, the following dimensions may be preferred. Preferably, the length **L1** (**Figure 3**) of the cable passages **144B** is at least 1.0 inch and, more preferably, between about 1.0 and 2.5 inch. Preferably, the length **L2** (**Figure 3**) of the sealant **160** is at least 0.75 inch and, more preferably, between about 0.75 and 2.25 inch. Preferably, the nominal diameter **D1** (**Figure 3**) of the cable passages **144B** is at least 1.0 inch. More preferably, the diameter **D1** is between about 1.0 and 2.0 inches. Preferably, the diameter **D1** is between about 15 and 30% greater than the diameter of the largest cable (including insulative cover) the port **144** is intended to accommodate. Preferably, the busbar assembly **100** is adapted to accommodate cables having a full diameter (including insulative cover) of between about 0.125 and 0.875 inch. Preferably, the expansion chamber **135** has a volume of at least 1.0 in^3.

Preferably, each closure wall **150** has a maximum thickness **T1** (**Figure 3**) of no more than 0.25 inch, and more preferably between about 0.005 and 0.125 inch. Preferably, each closure wall **150** has an insertion force (*i.e.*, force required to penetrate the plane of the closure wall **150** with the intended cable) of between about 1 lb. and 40 lbs and, more preferably, of between about 1 lb and 10 lbs. Each closure wall **150** may be molded with lines of reduced thickness or pre-cut or slotted after molding to create tear lines **150A** (**Figure 1**) that reduce the required assembly force to the desired level. Each closure wall **150** may be constructed as a membrane that substantially entirely seals the conductor passage **144B** prior to being ruptured.

With reference to **Figures 5-9**, a busbar assembly **200** according to further embodiments of the present invention is shown therein. The busbar assembly **200** includes a busbar conductor member **210**, a cover member **220**, four set screws **202**, four caps **252**, and four insert assemblies **270**. **Figure 9** shows an electrical connection assembly **201** including a cable **5** connected to the busbar assembly **200**.

The conductor member **210** includes conductor bores **212**, front openings **214** and threaded bores **218** corresponding to elements **112**, **114**, **118** as discussed above, except that the conductor bores **212** do not extend all the way through the conductor member **210**. However, it will be appreciated that the conductor bores **212** may be formed in the same fashion as the conductor bores **112**.

The cover member **220** is a one piece design and includes four access ports **234** corresponding to the access ports **134**. The cover member **220** also includes four cable ports **244** corresponding to the cable ports **144** except the cable passages **244B** preferably have a slightly larger interior diameter. The caps **252** are separately formed and adapted to removably seal the access ports **234**.

Each insert assembly **270** is positioned in a respective one of the cable ports **244**. Each insert assembly **270** has a sleeve member **272**. Each sleeve member **272** defines a passage **272A**, an entrance opening **272B**, and an exit opening **272C**. Each sleeve member **272** has an outwardly extending flange **272D** surrounding its entrance opening **272B**. A closure wall **274** extends across the passage **272A** of each sleeve member **272**. Each insert assembly **270** includes a mass of sealant **276** disposed in the passage **272A** thereof.

The sleeve members **272** may be formed of any suitable material. According to some embodiments, the sleeve members **272** are formed of a polymeric material such as polypropylene, polyethylene, or polyurethane.

According to some embodiments, the sealant **276** is a gel as described above. Each insert assembly **270** is positioned in the cable passage **244B** of the associated port **244** such that the sealant **276** is positioned between the entrance opening **244C** and the exit opening **244D** in the passage **244B** of the cable tube **244A**. The insert assembly **270** is maintained in position by the flange **272D**, which limits insertion depth, and a frictional fit, welding, adhesive or other suitable securement between the outer wall of the sleeve member **272** and the inner wall of the cable tube **244A**. Ribs **272E** extend lengthwise along and project into the passage **272A**. The ribs **272E** provide additional surface area for holding the sealant **276**.

Preferably, sleeve member passages **272A** and the masses of sealant **276** have dimensions corresponding to those discussed above with regard to the cable passages **144A** and the sealant **160**, respectively. According to some embodiments, the wall thickness of the sleeve member **272** is no greater than 0.125 inch.

The busbar assembly **200** may be used in the same manner as described above for the busbar assembly **100**. The busbar assembly **200** may be preferred for ease of assembly, particularly where a one-piece cover member **220** is desired.

The insert assemblies **270** may be separately molded or otherwise formed. The sealant **276**, such as a gel, may be installed in the sleeve members **272** by curing *in situ* in the manner described above for the cover member **240** and the gel sealant **160**. The cover member **220** may be molded about the conductor member **210** in conventional manner. The insert assemblies **270** may then be inserted into the respective cable ports **244** and suitably secured in place. The insert assemblies **270** may also be used to retrofit conventional busbar connectors.

With reference to **Figures 10** and **11**, a busbar assembly **300** according to further embodiments of the present invention is shown therein. The busbar assembly **300** corresponds to the busbar assembly **100**, except as follows. The access tubes **334A** of the access ports **334** are shortened and a cap assembly **380** is installed over each. Each cap assembly **380** includes a cap body **382** defining a passage **382A**. Each cap body **382** includes a flange **384** and a closure wall **386**. Each cap body **382** is secured, for example, by friction fit, welding, adhesive, snap latch and/or other suitable means, to a respective one of the access tubes **334A**. A mass of sealant **388**, preferably a gel as described above, is disposed in each passage **382A** and in an upper portion of the associated access tube **334A**. The masses of sealant **388** and the closure walls **386** serve to protect the busbar assembly **300** from the infiltration of moisture and/or contaminants.

The busbar assembly **300** may be used in the same manner as the busbar assembly **100** except that, in order to rotate each set screw **302** to secure or release a cable, the driver **9** is inserted through the closure wall **386** and the sealant **388**. After the screw **302** is positioned as desired, the driver **9** is withdrawn from the sealant **388**. Where, as preferred, the sealant **388** is a gel as described above, the gel **388** re-forms to again form a barrier to prevent or reduce infiltration of moisture and contaminants.

The cap bodies **382** are preferably formed of the same material as the sleeve members **272** as described above. The sealant (for example, a gel) may be installed in the same manner as the sealant **276**. According to alternative embodiments, the cap bodies **382** may be integrally formed with the access tubes **334A**.

With reference to **Figures 12** and **13**, a busbar assembly **400** according to further embodiments of the present invention is shown therein. The busbar

assembly **400** corresponds to the busbar assembly **100**, except as follows. The busbar assembly **400** includes a conductor member **410**, a cover assembly **420**, cover members **430**, **440**, and sealant **460** generally corresponding to the elements **110**, **120**, **130**, **140** and **160** discussed above, respectively. Each port **444** includes a cable tube **444A** defining a cable passage **444B**. The cable passage **444B** communicates with an entrance opening **444C** and an exit opening **444D**.

A penetrable closure wall **451** extends across the passage **444B** between the openings **444C** and **444D**. The closure wall **451** may be integrally molded with the tube **444A**. With reference to **Figure 13**, the closure wall **451** includes a plurality of discrete fingers or flaps **452** separated by gaps **452A**. The flaps **452** are flexible. According to some embodiments, the flaps **452** are also resilient.

According to some embodiments, the flaps **452** are concentrically arranged and taper inwardly in a direction **A** from the entrance opening **444C** to the exit opening **444D** to form a generally conical or frusto-conical shape. According to some embodiments, the angle of taper is between about 10 and 60 degrees. The closure wall **451** defines a hole **452B** that may be centrally located. According to some embodiments, the inner diameter **D2** of the hole **452B** is less than the outer diameter of the cable or cables (*e.g.*, the cables **5**, **7**) with which the assembly **400** is intended to be used. The thickness of the flaps **452** may taper in a radially inward direction. According to some embodiments, the thickness of the flaps **452** tapers in the radially inward direction at a rate of between about zero and 50 percent/inch.

An insert member **490** is positioned in the passage **444B** adjacent the exit opening **444D**. The insert member **490** is seated in a recess **444E** in the tube **444A** and positively captured between a ledge **444F** and the front face of the conductor member **410**. Additionally or alternatively, the insert member **490** may be otherwise secured within the passage **444B**, for example, by welding, adhesive, friction fit, a mechanical latch or latches, one or more fasteners or the like.

The insert member **490** includes a tubular body defining a passage **490A**. The insert member **490** further includes a penetrable closure wall **491** extending across the passage **490A**. The closure wall **491** may be integrally formed with the body **493**. The closure wall **491** may be constructed in the same manner as

discussed above with regard to the closure wall **451**, and includes a plurality of flaps **492** separated by gaps **492A** and defining a hole **492B**.

The closure walls **451** and **491** define a sealing chamber or region **499** therebetween (**Figure 13**). A portion **462** of the sealant **460** is disposed in the sealing region **499**. According to some embodiments, the sealant **462** substantially fills the sealing region **499**. A further portion **464** of the sealant **460** is disposed between the closure wall **491** and the conductor member **410**. A further portion **466** of the sealant **460** is disposed in the channel **436A**.

The assembly **400** may be used in the same manner as the assembly **100** to provided an environmentally protected connection between conductors (*e.g.*, of the cables **5**, **7**). Upon insertion of a cable through one of the ports **444**, the cable penetrates and displaces the closure wall **451**. The cable may elastically deflect the flaps **452** as the cable passes through the hole **452B**. As the cable is further inserted, the cable passes through and displaces the sealant portion **462**. The cable thereafter penetrates and displaces the closure wall **491** and passes into the interior cavity **422** of the housing **420**. The cable is inserted into the conductor member **410** and secured using the set screw as described above.

The closure walls **451** and **491** may serve to retain the sealant **462** in the sealing region **499** to improve the sealing performance of the connector assembly **400**. By retaining the sealant **462** in the sealing region **499**, a suitable amount of compressive force can be maintained between the sealant and the surfaces to be sealed. Moreover, a sufficient amount of the sealant may be retained in the sealing passage to re-form into a sealing plug upon removal of the cable from the port **444**. In the absence of the closure wall **491**, there may be a tendency for the cable to displace the sealant **462** into the interior cavity **422** so that there is insufficient sealant **462** remaining in the passage **444B** (and, more particularly, in the passage **499**) to effectively seal about the cable or to seal upon removal of the cable. The closure wall **451** may likewise serve to retain the sealant **462** in the sealing region **499** as the cable is withdrawn from the port **444**. The closure walls **451**, **491** may wipe the sealant **462** from the cable as the cable is inserted therethrough. Thus, the closure walls **451**, **491** may reduce the amount of sealant needed to provide the desired sealing performance, particularly in the case of multiple insertions and removals of the cable or cables.

Features directed to addressing other concerns may exacerbate the foregoing problems. For example, it may be desirable or even required that a chamber **435** be provided beyond the set screw **402** to allow an additional length of the conductor of the cable to be inserted into the conductor block **410**. This additional length may serve to provide a greater margin for error in installing the cable and to improve the integrity of the securement (*e.g.*, to reduce the risk of extruding the cable out from beneath the set screw **402**). However, the chamber **435** may allow an undesirably great amount of the sealant **462** to be displaced from the passage **444B**. The closure wall **491**, by preventing or limiting the displacement of the sealant **462** into the chamber **435**, allows for the provision of the chamber **435** without an undue loss of sealing performance.

The busbar assembly **400** may be formed in the same manner as the assembly **100** as discussed above. However, in the case of the assembly **400**, the insert member **490** may be placed in the recess **444E** before curing the sealant **460** (and typically before dispensing the uncured sealant into the front cover member **440**). In this manner, the sealant **460** may help to secure the insert member **490** in place in the front cover member **440**.

With reference to **Figure 14**, a busbar assembly **500** according to further embodiments of the present invention is shown therein. The busbar assembly **500** corresponds to the busbar assembly **200**, except as follows.

The busbar assembly **500** includes an insert assembly **570** in one or more ports **544** (one shown in **Figure 14**). The insert assembly **570** corresponds to the insert member **270**, except as follows. The insert assembly **570** has a penetrable closure wall **551** constructed as described above for the closure wall **451** in place of the frangible closure wall **274**. The insert member **570** additionally includes an insert member **590** corresponding to the insert member **490** and secured (*e.g.*, by holding, adhesive, friction fit, or other suitable means) in the passage **544A** of the sleeve **572**. The insert member **590** includes a further penetrable closure wall **591** constructed as described above for the closure wall **491**. The closure walls **551** and **591** define a sealing chamber or region **599** therebetween. Sealant **562** is disposed in the sealing region **599**. According to some embodiments, the sealant **562** substantially fills the sealing region **599**. According to some embodiments, and as shown, the sealant **562** extends to the exit opening **572C**.

The assembly **500** may be used in the same manner as the assembly **200** as described above. However, by provision of the additional closure wall **591**, the assembly **500**, and more particularly, the insert assembly **570**, can provide the advantages discussed above with regard to the busbar assembly **400**.

Where the closure walls **150**, **274**, **386**, **451**, **491**, **551** and **591** are elastically resilient, they will be spring biased against the outer surface of the inserted cable when displaced by the cable. This biased engagement may serve to enhance the engagement of the closure wall against the cable to thereby retain the pressure on the sealant. The biased engagement may also serve to improve the wiping effect as the cable is inserted or withdrawn. The geometry of the closure wall may further assist in improving the seal and wiping effect.

Various modifications may be made to the foregoing busbar assemblies **100**, **200**, **300**, **400**, **500** in accordance with the present invention. For example, the body sealant portion **164** may be omitted. According to some embodiments, the closure walls **150**, **274**, **386** may be omitted.

The closure walls **150**, **274**, **386** may be otherwise constructed so as to be penetrable and displaceable. For example, the closure walls **150**, **274**, **386** may be constructed in the manner described above for the closure walls **451**, **491**, **551**, **591**. Similarly, the closure walls **451**, **491**, **551**, **591** may be constructed so as to be fully or partly frangible. Closure walls of different designs and constructions may be used in the same connector as well as in the same port. For example, the outer closure wall may be frangible and formed as described for the closure wall **150** while the inner closure wall is formed as described for the closure wall **451**.

Moreover, various features of the above-described closure walls may be combined. For example, one or more of the closure walls may be frangible with a pre-formed hole corresponding to the hole **452B** formed therein and/or with a tapered shape. The closure walls including a plurality of flaps may be formed such that they do not form a pre-defined hole (*e.g.*, the hole **452B**). As a further alternative, each closure wall may be constructed as a resilient, elastic membrane or panel having a preformed hole therein, the closure wall being adapted to stretch about the hole to accommodate the penetrating cable without rupturing. In such case, the hole is preferably smaller in diameter than the outer diameter of the intended cable.

The insert assembly **570** may be of a one piece construction wherein the closure wall **591** is integrally molded with the sleeve **572** of the insert member **570**. The closure wall **491** may be integrally molded with or otherwise secured to the tube **444A** without using a separate insert member **490**, for example.

The inner closure walls (*e.g.*, closure walls **491, 591**) may be used without the outer closure walls (*e.g.*, closure walls **451, 551**). More than two closure walls may be employed. For example, a third closure wall may extend across the cable passage **444B** in the sealing region **499**.

While three or four cable ports and conductor bores and three or four access ports, screw bores and set screws are shown in each of the busbar assemblies **100, 200, 300, 400, 500**, busbar assemblies according to the present invention may include more or fewer cable ports and/or access ports and corresponding or associated components as needed to allow for the connection of more or fewer cables.

Various of the features and inventions discussed herein may be combined differently than in the embodiments illustrated. For example, the cap assemblies **380** may be used in the connector **200** as well.

While the present invention has been described herein with reference to busbar assemblies, various of the features and inventions discussed herein may be provided in other types of connectors. For example, the penetrable closure walls and insert assemblies may be employed in connectors for securing a single cable or the like.

While, in accordance with some embodiments, the sealants **160, 276, 388, 460, 562** are gels as described above, other types of sealants may be employed.

Connectors according to the present invention may be adapted for various ranges of voltage. It is particularly contemplated that multi-tap connectors of the present invention employing aspects as described above may be adapted to effectively handle voltages in the range of 120 to 1000 volts.

The foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly,

all such modifications are intended to be included within the scope of this invention. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the invention.